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EVALUATION OF SOIL AMENDMENTS FOR INCREASING NUTRIENTS IN ORGANIC FARMING

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Evaluation of Soil Amendments for Increasing Nutrients in Organic Farming

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Abstract/Summary

The overall objective of this project was to evaluate potential soil amendments for their ability to supply P and N to wheat and lentil crops grown under organic management. Specific objectives were to: 1) characterize the amendments with respect to nutrient compositions and potential toxic affects to germinating wheat, lentil and flax; 2) evaluate the amendments for providing P and N to organically managed wheat and lentil; 3) evaluate if select microbial inoculants improve wheat and lentil uptake of P and N from the organic amendments; and 4) investigate if growing wheat and lentil on organically managed soils affects different soil P pools. Seven amendments were evaluated: humic acids, composted sheep manure, alfalfa pellets, fresh poultry manure and aged poultry manure, and mustard and flax meal bioproducts of oil processing. Each of these amendments was applied to soil either alone or with one of two fungal inoculants [*Penicillium bilaiae* or arbuscular mycorrhizal fungi (AMF)] that work to improve soil P uptake by plants. Additionally the amendments were tested with worm castings which contain a broad spectrum of microorganisms along with some nutrients. The three animal manure amendments consistently produced the largest plants, with the highest P and N contents. Co-application of the amendment with any of the microbial products did not improve nutrient uptake. Furthermore, adding AMF to the soil as an inoculant did not improve the colonization of the roots with AMF. The organically managed soils contained high natural levels of AMF that successfully colonized the roots of both plant species. The plant-based amendments (alfalfa pellets, mustard and flax meals) were generally ineffective or inconsistently effective at supplying nutrients. Initially the alfalfa pellets completed inhibited germination of both wheat and lentil, but when the soil amended with the pellets was frozen (simulating a fall application and winter freeze) the inhibition was broken and seeds germinated. This freezing period also improved nutrient availability to the growing plants, possibly by accelerating decomposition. The mustard and flax meals generally appeared to be non-active, inert additions to the soil. They might similarly benefit from a freeze period to stimulate decomposition and nutrients release for plant growth. Finally, the two long-term organically managed soils used in the study were extracted to examine the size of different pools

of P. Based on the soil test values for extractable P, the 'Elbow' soil should have supported higher plant growth than the 'Vonda' soil, but the opposite was observed. The Vonda soil had a higher proportion of organic P than the Elbow soil, plus more P that is generally considered to be in a form relatively unavailable to plants. It appears that different pools of P might be more important in organically managed soils than conventionally fertilized soils where applied inorganic P supports growth.

Introduction

Widespread deficiency of P in organically managed soils exists across all of the major agricultural soil zones in Saskatchewan (ADF project # 20010016). Choices of organic fertilizers available for application on organically certified land are limited and can be very expensive. As farms continue to be managed organically for longer and longer periods of time, these deficiencies and deficiencies of other nutrients will become more severe and widespread. In a related study (ADF # 20010017) a number of experiments focused on soil amendments and green manures for supplying P to organically managed crops. Of all of the treatments tested, composted cattle manure provided the best nutrient supply and yield increases. Despite it performing well, it is not widely available to producers (unlesss they are themselves cattle producers), especially for application on a large scale. Additionally, although overall, the fungal inoculant *P. bilaiae* (JumpStart) did increase yields and P levels in the treatment year, the inoculant works to solubilize inherent soil P supplies and does not add any additional P to the system. Over the long term, application of this inoculant applied alone will serve to speed up the depletion of soil P supplies. Similarly, several green manure crops were identified that improved P fertility in the subsequent crop, but once again these green manures serve only to redistribute P in the soil, not add P to the system. There is a clear need for a range of inexpensive organic fertilizers that supply P to plants, in order to protect the sustainability of these organic farms.

Complicating matters further, are reports from producers that given the very low soil P values measured by traditional soil testing, crop yields are not depressed to the levels that are expected. It appears that in organic management, where mineral fertilizers are not applied, that other sources of P become more important than in conventional production systems. The most likely source of P are organically bound forms.

The overall purpose of this project was to evaluate potential organic amendments for their ability to supply P to growing wheat (*Triticum aestivum*) and lentil (*Lens culinaris*) crops. Only products with the potential to meet organic certification standards, as outlined in the National Standards of Canada (Government of Canada, 2006) were evaluated. In addition, the growth of wheat and lentil in organic soils was investigated for

its impact on soil P pools. Specific objectives were to: 1) characterize potential organic amendments with respect to nutrient compositions and toxicity to germinating wheat, lentil and flax; 2) evaluate potential organic amendments for providing P (and other nutrients) to organically managed crops; 3) evaluate if select microbial inoculants improve wheat and lentil uptake of P and N from the organic amendments; and 4) investigate if growing wheat and lentil on organically managed soils affects different soil P pools.

1. Methods

1.1 Description of organic amendments tested:

Seven organic amendments (Table 1) were evaluated for their ability to supply P and N to wheat and lentil test crops. In addition, each amendment was evaluated with arbuscular mycorrhizal fungi (AMF) inoculation, *Penicillium bilaiae* inoculation, and co-application with worm castings to determine if the microbial inoculants increased availability of the amendment. Worm castings were considered as a broad-spectrum microbial inoculant, because they harbour large, diverse microbial populations (Govedarica et al., 1991). However they were also evaluated for nutrient composition and their affect on germination and emergence and hence are included in Table 1.

Organically certified compost (Organic Green Earth) was obtained from Dutch Growers (Saskatoon, SK). The compost feedstock was sheep manure. Humic acids were supplied by Black Earth Humates (Edmonton, AB). Worm castings were obtained from Bustan, Urban Gardening Essentials (Toronto, ON). Organically certified alfalfa pellets were supplied by Western Alfalfa Milling Co. Ltd. (Norguay, SK). Poultry manure was obtained from Pineview Farms (Osler, SK). Although Pineview Farms is not organically certified, all products are produced without the use of hormones, antibiotics and other veterinary drugs. We obtained samples of fresh manure collected directly from the barns and aged manure that had been stock-piled outdoors for several years (the exact amount of time was not known). The manure was completely composted to a rich, black, earthy smelling composted material.

Table 1. Moisture and nutrient content of test products used to supply P and N to wheat and lentil test crops.

Property	Worm Castings [a]	Compost	Humic Acid	Alfalfa Pellets	Fresh Poultry Manure	Aged Poultry Manure	Mustard Meal	Flax Meal
Moisture (%)	55.4	53.5	9.1	4.3	20.0	27.3	0.2	0.2
N (lbs/ton)	13.1	9.4	18.8	42.4	75.9	27.5	118	126
P (lbs/ton)	0.7	5.5	69.5	2	22.5	37.7	17.8	15.1
K (lbs/ton)	1.5	12.4	272	28	26.5	9.1	17.5	20.1
S (lbs/ton)	1.6	2.1	4.8	3	10.9	6.4	28.8	6.2
Na (lbs/ton)	0.6	1.6	2.1	<1	10.4	1.9	<1.0	1.0
Ca (lbs/ton)	5.8	36.5	14.2	23	32.8	86.5	7.9	5.3
Mg (lbs/ton)	1.3	8.6	2.2	3	11.2	14.5	8.7	11.2
Cu (lbs/ton)	0.025	0.032	0.026	<0. 01	1.19	0.686	0.017	0.029
Fe (lbs/ton)	6.73	11.7	5.01	0.45	1.91	17.1	0.223	0.208
Mn (lbs/ton)	0.075	0.397	0.184	0.04	0.84	1.51	0.061	0.069
Zn (lbs/ton)	0.014	0.185	<0. 010	0.02	1.23	1.13	0.104	0.102

[a] Worm castings were evaluated as a source of microorganisms, not as a P and N source.

Mustard meal and flax meal was obtained from the Food and Bioproduct Sciences Department at the University of Saskatchewan. The meals were extrusion bi-products from a cold extraction process to extract the oil. While the meals were not guaranteed organic, there is potential for obtaining organically sourced mustard and flax as the feed stock for the process. Furthermore, the extrusion process itself is chemical free. The *P. bilaiae* inoculant was supplied by Novozymes Biologicals Ltd. (Saskatoon, SK). Myke^{Pro} AMF inoculants were obtained from Premier Tech Biotechnologies.

Originally we had canola meal for testing but replaced it with the mustard meal, since canola cannot be guaranteed organic. Subsamples of all of the amendments were analysed by ALS laboratories (Saskatoon, SK) for select macro- and micro-nutrients (Table 1).

1.2 Phytotoxicity assessment: germination and root length bioassays

All methods for the germination and root length bioassays were according to the US Composting Council, standard protocols (Leege and Thompson, 1997). Water-soluble extracts were obtained from each of the test products by suspending a known amount of the test product in a known volume of water. The ratio of product to water varied with the product to account for the different water holding capacities of the products. The final ratio used produced an extract volume of approximately 100 mL. Compost, humic acids and the aged poultry manure were sieved (4 mm mesh) to remove lumps. Three hundred and fifty grams of compost was extracted with 500 mL of deionized distilled water (ddwater). Two hundred grams of the aged poultry manure was extracted with 500 mL of ddwater. In both cases the resulting extractant was sterilized through 0.45 µm Millipore filters. After sieving, 100 g humic acid was suspended in 500 mL ddwater. The suspension could not be filtered directly without clogging the filter. It was first centrifuged at 15,000 rpm (5°C) and then filter sterilized through a 0.45 µm Millipore filter. The worm castings, alfalfa pellets, raw poultry manure and the mustard and flax meals were ground prior to extraction. Ratios of ground test product to water volume were as follows: worm castings, 200 g:250 mL; alfalfa pellets, 200 g:1000 mL; raw poultry manure, 200 g:500 mL; mustard meal, 100 g:500 mL; flax meal, 100 g:500

mL. All of the suspensions were first centrifuged (15,000 rpm; 5°C) and then filtered through 0.45µm Millipore filters.

The final filtrate was used 'as is' (100%) or as a 33% or a10% dilution made by diluting with sterile, ddwater. The lentil and wheat seed was soaked for 2 h in sterile ddwater prior to the assay. For each replicate, 10 seeds of the test crop (pre-soaked lentil, pre-soaked wheat and non-soaked flax) were placed in Petri dishes lined with filter paper. Three mL of the treatment extract (0, 10%, 33% or 100%) was pipetted onto the seeds. Five replicates of each treatment/test crop combination were tested. The plates were sealed in plastic bags to maintain humidity and incubated at 27°C for 48 h. At 48 h, 10 mL of 50% ethanol was added to each Petri plate to stop further germination and growth. Plates were refrigerated until they could be scored (within 2 days). Plates were scored for number of seeds germinated and root length. Germination was recorded as a percentage of the total number of seeds germinated (maximum of 100%). Root length was expressed as a percentage of the water control. For extracts that stimulate root growth, values are greater than 100%. For wheat, which has three distinct rootlets in the germinating radicle, a total of the three rootlet lengths was recorded and used in calculations. A 'Germination Index' (GI) was calculated which expresses the degree of stimulation or inhibition of root growth and germination relative to the water control, where:

GI = (% germination x % root length)/1000

Values <1 are indicative of overall inhibition and >1 indicative of stimulation.

1.3 Evaluation of organic amendments for providing P and N to organically managed crops

All amendments were evaluated in growth chamber experiments, in soil collected from organic farms. Two sources of soil were used over the course of the experiments, one collected from a single field on an organic farm near Elbow, SK and one from a field on an organic farm near Vonda, SK. Our original intent was to use only soil from Elbow throughout the experiment, but the farm changed ownership part way through the project and we were unable to re-access the original field. The Elbow farm is in the Brown soil zone. It had been farmed organically since 1990. The year prior to soil collection it had been cropped to wheat. The Vonda farm is on the border between the Dark Brown and

Black soil zones. It had been cropped organically since 1987. Like the field at Elbow, the field the soil was collected from was seeded to wheat the year prior to soil collection. Chemical and physical characterizations of the two soils are outlined in Table 2. Elbow soil was used for the compost and humic acid experiments and the evaluation of lentil with alfalfa pellets; Vonda soil was used for the alfalfa pellet experiment evaluating wheat, the poultry manure experiments and the mustard and flax meal experiments.

Table 2. Chemical and physical properties of soils to a 30 cm depth used in the organic amendment screening experiments.

	----------Soil source----------	
Characteristic	**Elbow**	**Vonda**
Texture	Loam	Loam
pH[a]	7.2	7.8
EC (mS/cm)[a]	0.2	0.1
NO_3-N (kg/ha)	17	11
P (kg/ha)	24	8.5
K (kg/ha)	724	460
SO_4-S (kg/ha)	33	20
Cu (kg/ha)	1.8	0.9
Mn (kg/ha)	19.7	8.3
Zn (kg/ha)	21.2	4.0
B (kg/ha)	2.9	3.2
Fe (kg/ha)	38	2.4

[a] 1 soil : 2 water extraction

Each of the organic amendments was evaluated in two separate experiments, one with wheat and one with lentil. Each of the amendments (compost, humic acids, alfalfa pellets, aged and fresh poultry manure, mustard meal and flax meal) was evaluated by itself and with a co-application of AMF, *P. bilaiae*, or worm castings, or a combination of the amendment, AMF and *P. bilaiae*. Except for the humic acids, which were applied according to the supplier's recommendations, and the alfalfa pellets (discussed below), the amount of organic amendment applied to each pot was based on the P content of the product. A rate equivalent to 40 kg per ha of each of the amendments was applied (Table 3). The amendment was applied to the surface of the soil and worked into the top 2.5 cm soil depth. According to the manufacturer's directions, a 6% suspension of the humic acids was prepared in water, and applied to the surface of the soil at a rate equivalent to 1 gallon per acre (9.4 L per ha; 3 mL per pot). After application the top 2.5 cm of soil was worked to incorporate the amendment.

Table 3. Amounts of P and N (kg per ha equivalent) added in each organic amendment treatment.

Amendment	P (kg/ha)	N (kg/ha)
Compost	40	68
Humic acids	2	0.5
Alfalfa pellets	1.2	24
Fresh poultry manure	40	135
Aged poultry manure	40	29
Mustard meal	40	265
Flax Meal	40	335

Worm castings were applied according to the manufacturer's recommendation. The equivalent of 10 lb per 100 ft^2 (15.4 g per pot) was applied to the soil surface and worked in to a 2.5 cm depth. This rate supplied the equivalent of 3.4 kg P per ha and 32 kg N per ha.

The granular AMF was applied at a rate equivalent to 6.6 lb per acre (20 mg per pot). The powdered AMF was applied at a rate of 0.15 g per m^2 (50 mg per pot). Both the granular and powdered AMF were applied to the soil surface and worked evenly into the top 2.5 cm. Rates and procedures were according to manufacturer's recommendations. The *P. bilaiae* spores for inoculant preparation were obtained from Novozymes Biologicals Ltd. (Saskatoon, SK). Enough inoculant was prepared to inoculate 1 kg of wheat or lentil seed. Two grams of spores containing 6×10^9 colony forming units (cfus) per gram were transferred into 98 mL of ddwater. A 13.3 mL aliquot of the suspension was used to inoculate 1 kg wheat seed; 6 mL of suspension was used to inoculate 1 kg lentil seed. This provided a minimum of 10^5 cfu per seed. The seed was placed in a re-sealable plastic bag and the appropriate amount of *P. bilaiae* suspension added to the bag. The sealed bag was massaged for several minutes to thoroughly and evenly coat the seeds. The seeds were planted within 1 h of inoculation.

Depending on the experiment 10 seeds of wheat or lentil were seeded into the pots after the amendment, AMF or worm castings were applied. Lentil was co-inoculated with a granular rhizobial inoculant (Novozymes Biologicals Ltd.) at seeding. Care was taken not to cross contaminate pots with the different inoculants. Only those pots receiving a particular inoculant were transported into the planting area during the inoculation process. Pots were watered to 80% field capacity. Ten replicates of each treatment were prepared. The pots were randomly placed in a growth chamber (16 h photoperiod, 22°C/16°C diurnal temperatures). Pots were watered as needed and water was readjusted to 80% field capacity weekly by weighing the pot and adding water to achieve the target weight. Pots were re-randomized at this time.

Plant emergence was recorded daily for 12 days after planting (DAP). Results for early emergence (5 DAP) and later emergence (11 DAP) are reported. At 12 DAP the 10 seedlings were thinned to 5 plants (wheat) or 3 plants (lentil). Six weeks after emergence one sub-set of 5 replicate pots was harvested by cutting the plants at soil level. The

second sub-set of 5 replicate pots was harvested approximately 90 DAP. Shoots were air dried, weighed, and a subsample acid digested and the digestate analysed for P and N using an autoanalyser. Total uptake of P and N from the pot was calculated. Roots from the final harvest were washed free of soil and stained and cleared (Vierheilig et al., 1998) and scored for percent AMF colonization (Giovannetti and Mosse, 1980). For the lentil experiments, nodules were removed from the root systems, counted and dried.

Alfalfa pellet experiments

Initially we applied the alfalfa pellets at the manufacturer's recommended rate of 2000 lb per acre, instead of basing it on the rate of P applied. If an equivalent rate of 40 kg P per ha had been used, 2.862 kg of N would also have been applied. Despite using the manufacture's recommended rate, germination of both the wheat and lentil was completely inhibited. In re-establishing the experiment we cut the rate in half; applying the equivalent of 1000 lb per acre (1121 kg per ha). Germination was still completely inhibited at this lower rate. It appeared as though the high water holding capacity of the alfalfa pellets was attracting any applied water, essentially creating drought conditions around the seeds. To test this, one of the five replicate pots per harvest was selected and the amount of water increased to try to compensate for what was perceived as a drought affect. However the alfalfa pellets in these pots rotted. These pots were discarded and the remaining four replicate pots were placed in a freezer at -20°C to simulate a fall application and subsequent winter freeze. The pots remained frozen for approximately 12 weeks. The pots were thawed at room temperature and watered to 80% field capacity. They were equilibrated at room temperature and maintained near 80% field capacity for 10 days to reestablish the microbial populations. The microbial inoculants were applied and the experiments seeded. Seeds of both wheat and lentil germinated after this freezing pre-treatment. Results reported are for this final experimental treatment where the alfalfa pellet-amended-soil was frozen.

Statistical analyses

The experimental designs for all of the organic amendment experiments were completely randomized designs with five replicates, except the alfalfa pellet experiment

that had four replicates. Wheat and lentil tested with each amendment were all run as separate experiments. Analysis of variance was run for each experiment using SPSS (ver. 16). Means separation was according to least significant differences at $P<0.05$. For the poultry manure experiment where both the fresh and aged poultry manures were tested in the same experiment orthogonal contrasts were performed.

2.4 Sequential extractions for phosphorus

The Elbow and Vonda un-amended control soils were subjected to sequential extractions (Tiessen and Moir, 1993) before and after the wheat and lentil was grown on it. The procedure uses a series of successively harsher extractants to release P from the different soil P pools. Readily available forms are released with the mild extractants whereas successively more unavailable forms are released by the increasingly harsh extractants. Organically bound forms of P (Po) are calculated as the difference between total P (Pt) and inorganic forms of P (Pi).

Briefly, the sequential extraction process involves first shaking a subsample of soil with deionized water (1 soil:60 water) with an anion exchange membrane. This represents the most easily extractable, water soluble P. The water is removed by centrifugation and the soil is further extracted with 0.5*M* $NaHCO_3$. Inorganic P and Pt are determined in the extract. The remaining soil was then extracted using 0.1*M* NaOH, followed by dilute (1*M*) HCl and finally concentrated HCl. The NaOH fractions and concentrated HCl fractions were analysed for Pi and Pt. The dilute HCl only extracts Pi. Po was calculated as the difference between Pt and Pi for the NaOH and concentrated HCl fractions.

The resin extractable and 0.5*M* $NaHCO_3$ extractions are thought to contain readily available P. The NaOH extractable and the dilute HCl extractable fractions contain strongly bound, relatively unavailable P and the concentrated HCl fractions the labile unavailable P.

2. Results and discussion

2.1 Phytotoxicity assessment: germination and root length bioassays

The potential exists for any amendment addition to the soil to negatively affect germination and seedling growth because of toxic compounds in the amendment. The US Composting Council has developed standardized protocols (Leege and Thompson, 1997) for assessing compost quality and the affect a particular compost has on germination and seedling growth. These protocols (used in our study) evaluate the affect that concentrated and dilute extracts from organic products have on germination and radicle growth. Different plant species can vary in their sensitivity to the extracts, so more than one species are tested. Because the amendments were being tested for agricultural applications we chose three agricultural test species from different families [lentil, Leguminosae (Fabaceae); wheat, Gramineae (Poacea); flax, Linaceae]. The affects on germination and root growth are combined in a germination index (GI) in which the combined effect is rated relative to a water control. Germination indices of 1.0 indicate no effect of the extract, values greater than 1.0 indicate overall stimulation by the extract and values less than 1.0 indicate overall inhibition by the extract.

Worm castings were applied in this study to introduce a broad spectrum of microorganisms into the soil, rather than to provide significant amounts of nutrients to the test plant. However, they were also evaluated in the germination and root growth assay. Extracts from worm castings generally had no inhibitory affect on GI except on lentil (Table 4a). Even the most dilute extracts (10%) seriously inhibited root growth and germination of lentil. Conversely, wheat and flax were either unaffected or stimulated by the extracts.

Lentil tended to be sensitive to many of the amendment extracts, especially the more concentrated extracts (Table 4a, 4b, 4c). Dilute humic acids (10%) stimulated both lentil germination and root length but higher concentrations severely inhibited these parameters. Only dilute solutions are recommended for use by the supplier. Composted sheep manure, alfalfa pellets, and fresh poultry manure all inhibited GI of lentil . Compost, in particular was strongly inhibitory even when applied as the most dilute

extract. Aged poultry manure had little affect at any concentration; mustard and flax meals were overall safe at any of the dilutions, but inhibitory when added as a concentrated extract (100%). The sensitivity of lentil to many of the amendments suggests that care should be taken to assess potential damage to a newly emerging lentil crop with the addition of any organic amendment.

In contrast to lentil, wheat and flax were either unaffected by the worm casting extracts or slightly stimulated by them. Compost was only a problem for flax when exposed to the most concentrated extract. Wheat was unaffected by any of the compost extracts. Like lentil exposure to the two highest concentrations of humic acids (33% and 100%) severely inhibited GI of both flax and wheat and even the 10% concentration severely inhibited flax GI. Based on these direct-exposure phytoxicity experiments humic acids should not be applied to fields in which flax will be grown. Flax was also very sensitive to alfalfa pellet extracts, fresh poultry manure and both the mustard and flax meals. Perhaps the extremely small seed size and hence high surface area to volume ratio of the seed makes flax seed more susceptible to toxic leachates. In addition the mucilaginous material surrounding flax seed after it has imbibed water, may serve to concentrate the toxins around the seed. Extracts from the worm castings and aged poultry manure were they only treatments that did not inhibit germination and root elongation in flax.

Table 4a: Germination (Germ.) and root growth of three test crops treated with water extracts from test amendments. Extract (%) refers to the percentage of extract relative to water: 0% is a water control; 100% is undiluted extract.

		Test Amendment								
		Worm castings			***Compost***			***Humic acids***		
Test crop	Extract (%)	Germ. (%)	Root length[a] (%)	GI[b]	Germ. (%)	Root length (%)	GI	Germ. (%)	Root length (%)	GI
Lentil	0	46	100	1.0	56	100	1.0	48	100	1.0
Lentil	10	32	73	0.5	24	25	0.1	66	169	2.3
Lentil	33	24	51	0.3	38	46	0.3	40	3.8	0.0
Lentil	100	34	72	0.5	22	22	0.1	0	0	0.0
Wheat	0	82	100	1.0	82	100	1.0	88	100	1.0
Wheat	10	86	129	1.4	90	106	1.2	90	67	0.7
Wheat	33	88	96	1.0	78	98	0.9	60	31	0.2
Wheat	100	88	99	1.1	78	82	0.8	20	1.8	0.0
Flax	0	68	100	1.0	74	100	1.0	80	100	1.0
Flax	10	76	128	1.4	74	86	0.9	76	26	0.3
Flax	33	68	109	1.1	88	104	1.2	14	1.3	0.0
Flax	100	78	134	1.5	68	44	0.4	0	0	0.0

[a] Root length is expressed as a percentage of the water control.

[b] Germination index (GI) expresses the degree of stimulation or inhibition of root growth and germination relative to the water control.

Table 4b: Germination and root growth of three test crops treated with water extracts from test amendments. Extract (%) refers to the percentage of extract relative to water: 0% is a water control; 100% is undiluted extract.

		Test Amendment								
		Alfalfa pellets			***Fresh Poultry manure***			***Aged Poultry manure***		
Test crop	Extract (%)	Germ. (%)	Root length[a] (%)	GI[b]	Germ. (%)	Root length (%)	GI	Germ. (%)	Root length (%)	GI
Lentil	0	36	100	1.0	84	100	1.00	92	100	1.0
Lentil	10	32	78	0.7	70	756	0.6	90	103	1.0
Lentil	33	16	15	0.1	74	55	0.5	90	91	0.9
Lentil	100	0	0	0.0	38	13	0.1	84	96	0.9
Wheat	0	78	100	1.0	96	100	1.0	96	100	1.0
Wheat	10	70	69	0.6	94	60	0.6	92	85	0.8
Wheat	33	46	13	0.1	96	50	0.5	98	87	0.9
Wheat	100	8	0.7	0.0	72	4	0	96	73	0.7
Flax	0	92	100	1.0	74	100	1.0	78	100	1.0
Flax	10	26	3.4	0.0	78	48	0.5	86	147	1.6
Flax	33	0	0	0.0	52	14	0.1	78	126	1.2
Flax	100	0	0	0.0	0	0	0	72	87	0.8

[a] Root length is expressed as a percentage of the water control.

[b] Germination index (GI) expresses the degree of stimulation or inhibition of root growth and germination relative to the water control.

Table 4c: Germination and root growth of three test crops treated with water extracts from test amendments. Extract (%) refers to the percentage of extract relative to water: 0% is a water control; 100% is undiluted extract.

		---------- *Test Amendment* ----------					
		------- *Mustard meal* -------			--- *Flax meal* ---		
Test crop	Extract (%)	Germ. (%)	Root length[a] (%)	GI[b]	Germ. (%)	Root length (%)	GI
Lentil	0	82	100	1.0	84	100	1.0
Lentil	10	78	98	0.9	90	121	1.3
Lentil	33	82	76	0.8	88	101	1.1
Lentil	100	42	23	0.1	64	29	0.2
Wheat	0	98	100	1.0	98	100	1.0
Wheat	10	94	71	0.7	94	63	0.6
Wheat	33	96	43	0.4	95	38	0.4
Wheat	100	72	18	0.1	72	3	0
Flax	0	70	100	1.0	76	100	1.0
Flax	10	62	62	0.5	70	51	0.5
Flax	33	26	22	0.1	5.4	9	0.1
Flax	100	0	0	0	0	0	0

[a] Root length is expressed as a percentage of the water control.

[b] Germination index (GI) expresses the degree of stimulation or inhibition of root growth and germination relative to the water control.

Extracts from the alfalfa pellets, fresh poultry manure and the mustard and flax meals also inhibited wheat GI, particularly the more concentrated extracts. Clearly it is not only the nutrients available from all of these organic amendments that will potentially influence growth of a crop; phytotoxic affects must also be considered. However, these tests are performed with water extracts from the amendment products. Unless exposed to very high moisture (rainfall) conditions it is unlikely that a germinating seed will be exposed directly to these leachates. Furthermore, except for flax, even in heavy rainfall conditions the excess moisture would drain away under gravity and not continuously bathe the germinating seed. These test do give us information on the potential for toxic affects developing. Of all of the amendments tested the aged poultry manure was the "safest" amendment, exhibiting very little inhibition to any of the test crops. This is also the amendment (excluding humic acids which are not applied on the basis of P content) with the highest concentration of P. Alfalfa pellets are widely available and are common amendments in reclamation and remediation. However, based on these tests they should be applied with care. All of the test crop seeds exhibited strong inhibition when exposed to alfalfa pellet extracts.

2.2 Evaluation of organic amendments for providing P and N to organically managed crops

Because the primary focus of this study was to evaluate amendments for their ability to supply P, of the organic amendments (except the humic acids and alfalfa pellets) were applied at rates equivalent to 40 kg P per ha which resulted in different additions of N to the soil (Table 3). On a per kg basis, the aged poultry manure had the highest content of P, followed by the fresh poultry manure and the mustard and flax meals. The composted sheep manure had a relatively low P content.

Basing the application rates on P content resulted in a wide range of N added with the amendments. The unbalance nature of these amendments could present problems with determining optimal application rates. Because these amendments are being tested for organic production, the option to apply the amendment based on N content and then supplement with P fertilizer to narrow the N:P ratio does not exist. Instead microbial

inoculants were tested in combination with the amendment to evaluate if they improved access to nutrients in the amendments.

2.2.1 Organic amendment evaluation

For each of the experiments an early harvest (approximately 6 weeks after emergence) was performed to evaluate the affect of the amendments on early P uptake. In a field situation, responses to P fertilization are frequently observed early in the growing season as roots develop, particularly under extended cool wet spring conditions. We saw no response in terms of growth or P uptake to any of the amendment applications at this early harvest stage (data not shown). The reason for the lack of response is probably two fold. First, growth chamber conditions are constant and do not mimic seasonal fluctuations in the field. The seedlings were never exposed to the cool, wet spring conditions that accompany early P responses in the field. Secondly, because of the organic nature of the amendments, the nutrients are not immediately available, as they are with an inorganic fertilizer application. Time is required for the amendments to decompose and the nutrients to mineralize and become available for plant uptake. For at least some of the amendments, responses were observed by the final harvest. Over the season, it is the final harvest that is important and ultimately translates into economic yield advantages. Final harvest results are summarized below.

Composted sheep manure

Application of the sheep manure compost affected nearly all of the wheat measurement parameters, except emergence (Tables 5a and 5b). Furthermore, application of the compost along with all of the microbial inoculants improved biomass production, as well as P and N tissue concentration and P and N uptake per pot. Application of compost by itself reduced AMF colonization probably because of inhibition due to the relatively high N content in the compost. Application of the compost with *P. bilaiae* seemed to provide some protection against the adverse affects on AMF colonization from the compost. Both treatments where *P. bilaiae* was applied had AMF levels comparable to the unamended controls (ca. 80%). Neither compost + AMF nor compost + worm

castings provided the same protection and AMF colonization in these treatments was comparable to the treatments receiving only compost (ca. 50%).

Despite the inhibition of AMF colonization in treatments with compost + AMF and compost + worm castings, the inoculants improved productivity and nutrient acquisition by wheat grown in these treatments compared to the controls. Both P and N uptake were improved by about 25% over both the control and the compost amended treatment when a microbial inoculant was applied.

Inoculation in addition to the compost amendment did not have the same affect on lentil growth and nutrient uptake as it did on wheat (Tables 6a and 6b). In the lentil experiment the compost added by it self resulted in the largest plants with the most N uptake in the shoots. Phosphorus uptake in the compost amended treatment was comparable to all of the other treatments and all of the treatments had close to twice as much P per pot compared to the unamended. Interestingly, the addition of compost stimulated nodulation in the lentil. It is often assumed that any high N containing fertilizer or amendment will inhibit nodulation. It is likely that the root systems developed nodules before N was mineralized from the added compost and the nodules were sustained through the experimental period. Nitrogen fixation was not measured directly but the interior of the nodules were pink, suggesting actively fixing nodules.

None of treatments affected AMF colonization. Like rhizobial symbiosis, application of any high-P-containing amendments or fertilizers is thought to impede AMF associations from developing. The AMF associations with the roots probably developed in the low P soil conditions prior to P becoming available from decomposition of the compost. Addition of AMF had no influence on AMF associations.

Table 5a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with **compost** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Control	2.0	8.4	6.12	80.0
Compost	0.2	6.4	6.30	54.8
Compost + *P. bilaiae*	1.6	7.2	7.68	77.2
Compost + AMF	1.6	7.6	7.75	53.8
Compost + *P. bilaiae* + AMF	2.6	7.4	7.17	80.0
Compost + worm castings	1.0	7.3	7.36	47.4
LSD (0.05)	1.6	2.2	0.91	7.1

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 5b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with **compost** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1.54	16.73	9.41	101.93	10.9
Compost	1.53	17.32	9.60	108.96	11.4
Compost + *P. bilaiae*	1.59	19.03	12.20	144.39	11.9
Compost + AMF	1.63	17.35	12.64	134.29	10.7
Compost + *P. bilaiae* + AMF	1.78	19.63	12.63	138.62	11.0
Compost + worm castings	1.71	19.45	12.59	142.67	11.5
LSD (0.05)	0.22	3.15	1.77	18.69	1.5

Table 6a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **lentil** grown in soil amended with **compost** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod No.	Nod dwt (mg)	AMF (%)
Control	1.0	3.4	2.75	124	33.35	72.0
Compost	0.4	4.6	4.51	248	70.25	78.2
Compost + *P. bilaiae*	1.2	3.6	3.98	193	59.45	81.4
Compost + AMF	0.2	5.0	4.34	182	49.76	78.2
Compost + *P. bilaiae* + AMF	1.2	2.6	3.59	201	65.96	77.4
Compost + worm castings	0.4	3.4	3.46	158	48.72	83.0
LSD (0.05)	0.94	2.0	0.81	76	0.01	9.6

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 6b. Nutrient concentration (mg/g) and uptake (mg/pot) by **lentil** grown in soil amended with **compost** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1.50	20.44	4.17	56.47	13.8
Compost	1.94	20.14	8.72	90.64	10.4
Compost + *P. bilaiae*	2.24	20.74	8.77	82.31	9.4
Compost + AMF	1.80	19.03	7.83	82.66	10.6
Compost + *P. bilaiae* + AMF	2.32	21.89	8.82	79.03	9.6
Compost + worm castings	2.15	21.24	7.47	72.47	9.9
LSD (0.05)	0.37	2.90	2.02	20.09	1.3

Humic acids

The addition of humic acids had no influence on wheat emergence, growth nor nutrient uptake, nor AMF colonization (Tables 7a and 7b). Humic acids and co-application of worm castings delayed emergence and ultimately resulted in small plants at harvest. Consequently the small plants extracted less P and N from the soil than all other treatments including the control. It appears as though the humic acid solution added to the soil amended with worm castings caused compounds that are toxic to wheat to be released from the worm castings. This is clearly not a good combination of amendments for wheat growth.

Lentil similarly did not show any improvement in growth nor nutrient uptake with the addition of humic acids to the soil (Table 8a and 8b). Co-application with any of the microbial inoculants did not improve nutrient uptake, but also did not negatively affect growth or nutrient uptake. Application of humic acids is not recommended.

Alfalfa pellets

In the initial experiment where alfalfa pellets were applied to the soil emergence of both wheat and lentil was completely inhibited. The experiment was set up again using new seed and freshly prepared inoculants and wheat and lentil emergence was again completely inhibited. The reason for the inhibition appeared to be two-fold, firstly there were probably direct phytotoxic affects from the alfalfa pellets as were seen in the phytotoxicity test with water extracts from the alfalfa pellets (Table 4b, section 3.1). Secondly the alfalfa pellets, because of their organic nature, had a high water-holding capacity. The pellets appeared to bind the water, essentially creating a drought for the germinating seeds. We selected a subset of one of the five replicates and tried increasing the amount of water applied to each pot in an attempt to overcome this problem, but the pellets rotted. Our final test was to place the remaining four replicate pots for each treatment in a -20°C freezer, to simulate fall application and subsequent winter freeze cycle.

Table 7a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with **humic acids** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Control	2.0	6.8	6.13	80.0
Humic acids	0.6	7.4	5.81	65.6
Humic acids + *P. bilaiae*	2.0	7.0	6.89	79.2
Humic acids + AMF	2.4	6.0	6.37	72.8
Humic acids + *P. bilaiae* + AMF	3.2	7.8	5.84	74.0
Humic acids + worm castings	0	2.8	3.11	72.8
LSD (0.05)	1.8	2.3	1.29	7.7

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 7b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with **humic acids** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1.54	16.73	9.41	101.93	10.9
Humic acids	1.72	21.39	10.02	124.34	12.4
Humic acids + *P. bilaiae*	1.65	15.35	11.41	103.80	9.2
Humic acids + AMF	1.77	14.59	11.24	93.53	8.3
Humic acids + *P. bilaiae* + AMF	1.96	16.10	11.42	93.05	8.2
Humic acids + worm castings	2.06	10.09	6.74	36.82	4.9
LSD (0.05)	0.26	5.51	2.88	11.15	2.6

Table 8a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **lentil** grown in soil amended with **humic acids** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod No.	Nod dwt (mg)	AMF (%)
Control	1.0	3.4	2.75	124	33.4	72.0
Humic acids	1.4	5.4	3.40	149	45.8	76.6
Humic acids + *P. bilaiae*	0.6	4.4	3.43	144	33.3	69.6
Humic acids + AMF	0.8	6.0	3.42	200	24.9	80.3
Humic acids + *P. bilaiae* + AMF	1.4	4.0	2.36	107	32.6	76.0
Humic acids + worm castings	2.2	5.0	2.90	100	40.4	81.0
LSD (0.05)	1.4	2.1	0.52	71	0.6	10.1

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 8b. Nutrient concentration (mg/g) and uptake (mg/pot) **lentil** grown in soil amended with **humic acids** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1.50	20.44	4.17	56.47	13.8
Humic acids	1.33	18.56	4.50	63.31	14.0
Humic acids + *P. bilaiae*	1.33	19.67	4.64	68.66	15.1
Humic acids + AMF	1.45	20.24	4.98	69.71	14.1
Humic acids + *P. bilaiae* + AMF	1.10	15.59	2.59	36.70	14.3
Humic acids + worm castings	1.31	18.02	3.81	52.46	14.0
LSD (0.05)	0.27	3.22	2.78	32.28	2.2

The pre-freezing treatment was successful in eliminating the inhibition of germination of wheat (Table 9a and 9b) and even stimulated early emergence in wheat. The freezing treatment visibly stimulated the breakdown of the alfalfa pellets. The treatments with alfalfa pellets co-inoculated with *P. bilaiae* and/or AMF all produced more biomass that the control and treatments not inoculated with *P. bilaiae* or AMF. There was also a slight increase in AMF colonization with all of the treatments, but even the controls had very high colonization percentages. Alfalfa pellets added with all of the microbial inoculants except the worm castings increased shoot dry weight and shoot P and N uptake per pot. Tissue concentrations of P increased in all treatments but shoot N concentrations did not and tended to be slightly lower compared to the control treatment. Considering the very high N content in the alfalfa pellets, it is surprising that the affect of tissue P was more evident that the effect on tissue N. Overall average dry mass in the three treatments receiving alfalfa pellets and *P. bilaiae* and/or AMF increased by slightly more than 40%, P uptake increase by approximately 60% and N uptake by about 50%.

This was the first experiment that used the Vonda soil instead of the Elbow soil. In terms of available macronutrients the Elbow soil had more N, P and S than the Vonda soil (Table 2). Surprisingly, wheat plants grown in the control treatments using the Vonda soil tended to have approximately double the concentration of P and N in the shoots. There is clearly some other feature of the soil that is influencing nutrient availability, other than extractable nutrient contents. Soils with higher organic matter contents have a greater potential to supply nutrients over the growing season as the organic matter decomposes and nutrients are mineralized.

Table 9a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with **alfalfa pellets** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Control	2.0	8.4	5.12	80.0
Alfalfa pellets	8.5	9.3	5.99	94.8
Alfalfa pellets + *P. bilaiae*	7.5	8.8	7.31	93.3
Alfalfa pellets + AMF	3.0	5.5	7.51	91.2
Alfalfa pellets + *P. bilaiae* + AMF	8.3	8.5	7.12	93.0
Alfalfa pellets + worm castings	5.3	9.3	5.97	97.0
LSD (0.05)	2.9	2.7	0.99	3.7

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 9b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with **alfalfa pellets** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	3.49	31.52	20.37	134.21	9.1
Alfalfa pellets	3.90	25.08	23.22	150.58	6.4
Alfalfa pellets + *P. bilaiae*	4.83	29.12	35.19	212.29	6.0
Alfalfa pellets + AMF	4.39	26.52	33.01	199.27	6.0
Alfalfa pellets + *P. bilaiae* + AMF	4.36	28.23	31.34	202.44	6.5
Alfalfa pellets + worm castings	4.24	25.49	25.31	152.22	6.0
LSD (0.05)	0.39	1.93	3.86	26.51	0.4

Emergence of lentil continued to be inhibited somewhat by the alfalfa pellets even after the freezing treatment (Table 10a and 10b). Furthermore variability was higher for most of the measurement parameters (indicated by the higher LSD values in this experiment than others), perhaps reflecting only partial breakdown of the alfalfa pellets. Lentil seemed to be more affected than wheat. Nodulation was drastically inhibited by the alfalfa pellets. Only the alfalfa pellet + *P. bilaiae* treatments had nodule numbers similar to the controls. Despite the higher numbers of nodules produced by plants in this treatment, the nodules were extremely tiny weighing the same amount as the few large nodules developing in the other treatments. Arbuscular mycorrhizal fungi colonization was very high even in the unamended control. Despite the high overall levels of AMF infection, all of the treatments stimulated AMF colonization about 20% above the control. Despite the extremely variable affect that the alfalfa pellet treatments had on dry matter production, shoot P and N concentrations and uptake were all increased. Co-application of *P. bilaiae* with the alfalfa pellets and co-application with alfalfa pellets, *P. bilaiae* and AMF also were the two most effective treatments in increasing P uptake. Shoot P uptake in these two treatments doubled. Nitrogen uptake also was increased in two of the treatments (Alfalfa pellets + *P. bilaiae* + AMF and Alfalfa pellets + worm castings). However the extremely variable nature of this data makes it difficult to draw general conclusions or make recommendations. While there is evidence that the alfalfa pellets are providing nutrients to the growing lentil plant, there also seems to be some toxic allelopathic affects that lentil is particularly sensitive to.

Table 10a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **lentil** grown in soil amended with **alfalfa pellets** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod no.	Nod dwt (mg)	AMF (%)
Control	0.4	5.2	2.92	125	42.8	81.2
Alfalfa pellets	0	2.8	1.75	2.8	6.80	99.3
Alfalfa pellets + *P. bilaiae*	0	6.5	4.00	70.3	7.02	99.5
Alfalfa pellets + AMF	0	3.0	2.50	3.5	6.03	99.8
Alfalfa pellets + *P. bilaiae* + AMF	0	1.3	1.00	1.5	3.63	100
Alfalfa pellets + worm castings	0	3.5	2.25	4.0	7.67	100
LSD (0.05)	0.01	3.7	2.24	77.1	3.9	1.0

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 10b. Nutrient concentration (mg/g) and uptake (mg/pot) by **lentil** grown in soil amended with **alfalfa pellets** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Alfalfa pellets	1.41	18.09	4.27	53.45	13.2
Alfalfa pellets + *P. bilaiae*	2.74	29.76	5.71	62.64	10.9
Alfalfa pellets + AMF	2.12	25.68	9.18	77.95	9.9
Alfalfa pellets + *P. bilaiae* + AMF	1.84	37.88	3.66	78.40	20.7
Alfalfa pellets + worm castings	2.26	31.43	8.41	122.37	14.6
LSD (0.05)	2.28	32.79	7.86	114.06	14.6
	0.42	2.30	4.86	52.05	4.3

Poultry manure:

The aged and fresh poultry manures were examined for their affect on wheat germination, growth and nutrient uptake in a single experiment (Tables 11a and 11b). Like many of the amendments tested, application of the poultry manure delayed early emergence. By 11 DAP wheat emergence was still slightly lower than the controls for most treatments. Both the aged and fresh manures increased wheat shoot dry weight dramatically. The application of an inoculant with the fresh manure increased shoot dry weight compared to fresh manure alone, but application of an inoculant with the aged manure slightly decreased shoot dry weight compared to aged manure alone. All of the treatments reduced AMF colonization compared to the control and the treatments in which AMF was introduced did not improve colonization.

Overall the amendments slightly increased P concentrations but slightly decreased N concentrations. This reflects that fact that on a relative basis, P uptake was increased to a greater degree than N uptake. The larger plants diluted the concentration of N in the tissue but P uptake was relatively more than N and concentrated slightly in the tissues. Phosphorus uptake was increase 1.4 times by the addition of fresh manure and an average of 1.9 times when the fresh manure was also inoculated with any of the inoculants. The aged manure applied alone doubled P uptake, whereas co-inoculation of the aged manure increased P uptake by 1.5 times. Enhancement of N uptake by wheat was between 1 and 1.5 times that of the control. Inoculation of fresh manure resulted in the biggest enhancement of N uptake. Considering that the N content of the fresh manure was substantially more than the aged manure (135 kg/ha vs 29 kg/ha) (Table 3) it is not surprising that fresh manure had a larger impact on N uptake. What is more surprising is that the impact was not larger than it was.

Lentil responded in a similar manner as wheat to the poultry manure applications (Table 12a and 12b). Shoot dry weight approximately doubled in all of the treatments except the application of fresh manure where it increased by 40%. The largest difference between the fresh manure and the aged manure was the affect on nodulation and AMF colonization. Lentil grown with the aged poultry manure had 3 times more nodules than lentil grown with the fresh manure. Aged manure + worm castings also had more than twice as many nodules as the same treatment with fresh manure.

Table 11a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with fresh or aged **poultry manure** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

	Trt no.	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Treatment					
Control	1	8.0	9.4	1.25	58.4
Fresh manure	2	3.6	7.8	2.78	44.6
Fresh + *P. bilaiae*	3	3.8	8.8	3.58	47.2
Fresh + AMF	4	4.2	6.6	3.76	44.4
Fresh + *P. bilaiae* + AMF	5	5.4	8.8	3.26	39.4
Fresh + worm castings	6	6.6	8.4	3.08	44.6
Aged manure	7	2.8	6.4	3.61	38.2
Aged + *P. bilaiae*	8	5.4	8.2	3.08	36.2
Aged+ AMF	9	4.6	7.4	3.02	41.2
Aged + *P. bilaiae* + AMF	10	3.4	7.2	2.79	41.6
Aged + worm castings	11	2.6	6.6	3.56	35.6
LSD (0.05)		*1.4*	*1.3*	*0.32*	*7.1*
Orthagonal contrasts	***Trts compared***	***P value***	***P value***	***P value***	***P value***
Control vs all treatments	1 vs 2,3,4,5,6,7,8,9,10,11	0.000	0.017	0.000	0.000
Fresh vs Aged	2,3,4,5,6 vs 7,8,9,10,11	0.038	0.039	0.447	0.023
Fresh vs Fresh + amendment	2 vs 3,4,5,6	0.085	0.650	0.001	0.865
Aged vs Aged + amendment	7 vs 8,9,10,11	0.138	0.221	0.011	0.913

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 11b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with fresh or aged **poultry manure** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Trt no.	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1	3.49	31.52	20.37	184.21	9.1
Fresh manure	2	3.57	27.29	47.95	366.75	7.7
Fresh + *P. bilaiae*	3	3.50	32.84	58.71	551.49	9.4
Fresh + AMF	4	3.71	26.68	64.16	462.76	7.2
Fresh + *P. bilaiae* + AMF	5	3.78	26.89	58.56	418.24	7.1
Fresh + worm castings	6	3.70	28.96	54.90	430.16	7.9
Aged manure	7	3.69	25.10	60.65	413.28	6.8
Aged + *P. bilaiae*	8	3.67	28.57	53.01	412.53	7.8
Aged+ AMF	9	3.72	31.85	53.09	453.92	8.6
Aged + *P. bilaiae* + AMF	10	3.57	26.99	47.32	357.19	7.6
Aged + worm castings	11	3.39	29.45	54.32	472.09	8.7
LSD (0.05)		*0.19*	*1.45*	*5.16*	*44.42*	*0.46*
Orthagonal contrasts	***Trts compared***	***P value***	***P value***	***P value***	***P value***	***P value***
Control vs all treatments	1 vs 2,3,4,5,6,7,8,9,10,11	0.179	0.000	0.000	0.000	0.000
Fresh vs Aged	2,3,4,5,6 vs 7,8,9,10,11	0.442	0.767	0.068	0.107	0.755
Fresh vs Fresh + amendment	2 vs 3,4,5,6	0.348	0.072	0.001	0.000	0.367
Aged vs Aged + amendment	7 vs 8,9,10,11	0.364	0.000	0.006	0.682	0.000

Table 12a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **lentil** grown in soil amended with fresh or aged **poultry manure** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Trt no.	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod no.	Nod dwt (mg)	AMF (%)
Control	1	4.8	5.2	4.15	21.4	1.5	82.6
Fresh manure	2	2.6	2.6	5.81	56.6	1.4	63.2
Fresh + *P. bilaiae*	3	2.2	2.6	7.97	80.0	16.3	62.2
Fresh + AMF	4	1.4	1.8	5.55	46.4	7.4	63.8
Fresh + *P. bilaiae* + AMF	5	2.4	3.2	7.27	85.0	19.4	69.0
Fresh + worm castings	6	3.8	3.6	7.98	73.2	22.1	75.6
Aged manure	7	5.6	5.6	8.72	234.2	81.8	80.4
Aged + *P. bilaiae*	8	4.2	4.2	8.26	119.2	46.4	73.8
Aged+ AMF	9	4.4	5.4	7.93	172.4	55.9	77.0
Aged + *P. bilaiae* + AMF	10	5.0	5.4	7.35	128.0	35.8	70.8
Aged + worm castings	11	5.6	6.0	8.58	219.8	61.3	83.6
LSD (0.05)		*1.33*	*1.35*	*1.60*	*60.9*	*0.027*	*10.5*
Orthagonal contrasts	***Trts compared***	***P value***	***P value***	***P value***	***P value***	***P value***	***P value***
Control vs all treatments	1 vs 2,3,4,5,6,7,8,9,10,11	0.146	0.122	0.00	0.004	0.002	0.071
Fresh vs Aged	2,3,4,5,6 vs 7,8,9,10,11	0.000	0.000	0.022	0.000	0.000	0.005
Fresh vs Fresh + amendment	2 vs 3,4,5,6	0.848	0.800	0.145	0.684	0.821	0.472
Aged vs Aged + amendment	7 vs 8,9,10,11	0.309	0.658	0.460	0.042	0.007	0.508

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 12b. Nutrient concentration (mg/g) and uptake (mg/pot) by **lentil** grown in soil amended with fresh or aged **poultry manure** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Trt no.	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	1	3.06	27.76	12.65	114.59	9.1
Fresh manure	2	2.64	22.00	15.33	122.96	8.4
Fresh + *P. bilaiae*	3	3.03	24.80	24.04	191.10	8.2
Fresh + AMF	4	2.89	24.56	15.67	133.82	8.5
Fresh + *P. bilaiae* + AMF	5	3.01	25.38	22.20	181.92	8.5
Fresh + worm castings	6	2.73	23.28	21.73	183.49	8.5
Aged manure	7	3.30	21.93	28.87	192.03	6.6
Aged + *P. bilaiae*	8	2.78	18.98	22.83	156.15	6.8
Aged+ AMF	9	3.05	21.91	24.41	174.80	7.2
Aged + *P. bilaiae* + AMF	10	2.92	22.29	21.45	163.04	7.6
Aged + worm castings	11	3.25	23.04	27.92	198.68	7.1
LSD (0.05)		*.26*	*.88*	*5.13*	*38.59*	*0.7*
Orthagonal contrasts	***Trts compared***	***P value***	***P value***	***P value***	***P value***	***P value***
Control vs all treatments	1 vs 2,3,4,5,6,7,8,9,10,11	0.486	0.002	0.001	0.012	0.001
Fresh vs Aged	2,3,4,5,6 vs 7,8,9,10,11	0.024	0.013	0.003	0.267	0.000
Fresh vs Fresh + amendment	2 vs 3,4,5,6	0.071	0.131	0.068	0.032	0.945
Aged vs Aged + amendment	7 vs 8,9,10,11	0.052	0.820	0.121	0.406	0.202

Similarly AMF colonization was reduced with the application of fresh poultry manure. Arbuscular mycorrhizal colonization percentages approached the unamended control percentages.

Shoot uptake of P and N by lentil also improved with all of the poultry manure applications except the fresh manure and the fresh manure + AMF treatments. The enhancement of nutrient uptake was not as substantial as it was with wheat. Phosphorus uptake was improved an average of 90% and N uptake by 60% in those treatments that significantly affected nutrient uptake. It appears that addition of the fresh poultry manure negatively affected the microbial populations around the roots, affecting rhizobia and AMF populations specifically and possibly other unidentified flora as well. While the fresh poultry manure provided nutrients directly, it appears to have interfered with lentil's ability to acquire nutrients through N fixation and AMF colonization.

Despite its lower N content, application of well-rotted (or composted) poultry manure is probably a safer choice for the overall health of the soil ecosystem. Nutrient extraction by wheat or lentil from the aged poultry manure was not enhanced by the introduction of microbial inoculants.

Mustard meal:

Application of mustard meal at a rate equivalent to supplying 40 kg P/ha results in a co-application of 265 kgN/ha (Table 3). Despite the high amounts of nutrients added there was no positive affect on wheat growth nor nutrient uptake (Tables 13a and 13b). The meal resulting after the oil was extracted from the mustard seed was a very tough, fibrous material presumably containing a lot of cell wall cellulose and hemicellulose and lignified materials that are difficult to degrade. Furthermore, there was little significant affect of this material on AMF colonization in wheat roots. Mustard is a member of the Brassicacae family, which do not form associations with AMF. Furthermore, members of the mustard family inhibit colonization of AMF in mycorrhizal rotation crops grown the year after the brassica. It was expected that the addition of mustard meal would function similarly to mustard in a crop rotation. The lack of an affect on wheat AMF colonization

suggests that the mustard meal material added was essentially non-reactive and served mainly as a neutral addition to the soil.

Table 13a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with **mustard meal** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Control	6.8	7.6	10.14	46.4
Mustard	5.6	6.6	10.23	47.8
Mustard + *P. bilaiae*	2.6	3.6	7.89	27.8
Mustard + AMF	5.2	6.2	9.90	41.6
Mustard + *P. bilaiae* + AMF	3.4	4.8	8.33	36.8
Mustard + worm castings	4.4	5.8	9.41	43.2
LSD (0.05)	1.8	1.7	1.92	11.0

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 13b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with **mustard meal** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	4.12	23.20	40.99	231.09	5.6
Mustard	4.30	25.34	43.61	259.91	5.9
Mustard + *P. bilaiae*	4.82	27.49	37.75	216.02	5.7
Mustard + AMF	4.84	25.91	47.74	256.34	5.4
Mustard + *P. bilaiae* + AMF	4.70	27.67	38.77	228.22	5.9
Mustard + worm castings	4.70	25.77	44.04	241.97	5.5
LSD (0.05)	*0.54*	*1.52*	*8.43*	*48.20*	*0.6*

When the mustard meal was co-applied with a microbial inoculant there was some tendency for dry weight production to be reduced as well as AMF colonization, although only the mustard meal + *P. bilaiae* treatment was statistically significant. It may be that the microorganisms enhanced degradation slightly but rather than benefiting the wheat by solubilizing nutrients, the allelopathic affects of the mustard were enhanced.

The affect of the mustard meal on lentil was similar to its affect on wheat in that there was generally little improvement in nutrient uptake or growth (Fig 14a and 14b). Amending the soil with mustard meal dramatically reduced lentil nodulation and to a lesser degree AMF colonization. None of the mustard meal treatments improved lentil shoot P nor N uptake. The reduced nodulation caused by the mustard meal indicates some toxic affects to soil organisms. Mustard meal is not an effective amendment for improving nutrient uptake by either wheat or lentil.

Flax Meal:

Amending the soil with flax meal delayed wheat emergence at both 5DAP and 11DAP (Tables 15a and 15b). Similar to the alfalfa meal and mustard meal additions the hydrophilic nature of the amendment might serve to bind water effectively interfering with imbibition of the seed. In general, flax meal amendment had little affect on shoot biomass production, although the application of flax meal with *P. bilaiae* reduced shoot biomass relative to some of the other treatments but not the unamended control. AMF colonization was unaffected by any of the treatments indicating that unlike the mustard meal there did not appear to be toxic affects to the AMF community due to the application of the flax meal. The only treatment to significantly affect shoot P uptake was the Flax meal + *P. bilaiae* treatment that had lower P uptake than the other treatments and the control. This treatment also reduced shoot N uptake by wheat, which was probably a result of the smaller plants rather than reduced active uptake of N. Although shoot P concentrations were not affected by the flax meal amendments, the flax meal did provide N to the growing wheat crop. Both shoot N concentration and shoot N uptake were increased in all of the treatments except the Flax + *P. bilaiae* treatment.

Table 14a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **lentil** grown in soil amended with **mustard meal** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod no.	Nod dwt (mg)	AMF (%)
Control	2.8	3.8	8.47	451.8	35.7	59.8
Mustard	7.0	9.2	10.24	91.6	30.0	49.2
Mustard + *P. bilaiae*	6.4	10.8	8.75	127.0	4.9	47.2
Mustard + AMF	5.4	5.4	6.95	113.6	14.7	34.2
Mustard + *P. bilaiae* + AMF	6.6	7.2	10.91	184.8	12.5	54.8
Mustard + worm castings	12.4	12.6	12.03	219.2	7.9	53.8
LSD (0.05)	3.1	3.1	2.27	145.4	0.012	12.3

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 14b. Nutrient concentration (mg/g) and uptake (mg/pot) by **lentil** grown in soil amended with **mustard meal** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	4.46	22.83	37.75	192.66	5.1
Mustard	3.80	26.48	38.99	269.31	7.0
Mustard + *P. bilaiae*	3.79	25.17	33.47	219.49	6.7
Mustard + AMF	3.90	29.47	26.69	202.79	7.6
Mustard + *P. bilaiae* + AMF	3.70	22.99	40.54	247.21	6.3
Mustard + worm castings	3.52	23.53	42.35	281.42	6.7
LSD (0.05)	0.28	1.87	9.52	47.99	0.77

Table 15a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of **wheat** grown in soil amended with **flax meal** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	AMF (%)
Control	6.4	7.8	9.38	47.8
Flax	4.2	4.8	11.06	46.0
Flax + *P. bilaiae*	1.6	2.0	7.97	44.0
Flax + AMF	3.8	4.6	10.74	42.0
Flax + *P. bilaiae* + AMF	2.6	2.8	10.21	46.2
Flax + worm castings	3.8	3.8	10.31	41.4
LSD (0.05)	1.6	1.5	2.00	10.4

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 15b. Nutrient concentration (mg/g) and uptake (mg/pot) by **wheat** grown in soil amended with **flax meal** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant..

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	4.48	19.67	41.99	184.38	4.4
Flax	4.14	25.16	43.78	267.28	6.1
Flax + *P. bilaiae*	4.22	24.31	33.63	194.87	5.9
Flax + AMF	4.22	23.46	45.29	254.76	5.6
Flax + *P. bilaiae* + AMF	4.28	28.38	43.52	290.64	6.6
Flax + worm castings	4.18	25.74	42.61	266.87	6.20
LSD (0.05)	0.38	2.04	7.90	61.21	.85

Lentil emergence was also slightly delayed by the flax meal soil amendments at both 5 and 11 DAP (Table 16a). As was the case with mustard meal, addition of flax meal to the soil dramatically reduced nodulation of lentil, but unlike mustard meal, AMF colonization was not affected (Table 16b). Inoculation with *P. bilaiae* in combination with the flax meal seemed to provide some degree of protection from the negative effects of the flax meal. This one treatment had higher nodulation numbers than the other treatments although nodulation was lower than the control. However, the nodules that did form were smaller than nodules on the other treatments, indicated by the second lowest nodule dry weight of all of the treatments.

Flax meal applied by itself was the only treatment to improve shoot N uptake compared to the control. Shoot P uptake had a tendency to be higher, but the difference was not statistically significant. Inoculation with any of the microbial inoculants did not improve nutrient uptake by lentil.

Neither the mustard nor flax meals provided significant nutrients to the growing plants despite the very high N levels. At least in the year of application it appears that the lignified nature of the amendments minimizes decomposition of the meals. As was the case with the alfalfa pellets, these amendments might benefit from a fall application with a winter freeze before seeding the following spring - although this would need to be evaluated. Because emergence was not completely inhibited we did not apply this strategy to these amendments.

An additional consideration with these very high N containing organic products is that when they do decompose the N mineralized could be subject to leaching and/or denitrification depending on the environmental status. Optimal rates of application would need to be determined based on N content and mineralization potential rather than P content as was done in this study. Under the conditions of this study the meals did not improve P nutrition to a growing crop.

Table 16a. Growth characteristics and arbuscular mycorrhizal fungi (AMF) infection of lentil grown in soil amended with **flax meal** alone or with combinations of worm castings, *Penicillium bilaiae* and AMF inoculant.

Treatment	Emerg. 5 DAP [a]	Emerg. 11 DAP [a]	Sht dwt (g)	Nod no.	Nod dwt (mg)	AMF (%)
Control	3.8	4.6	8.05	384.0	4.45	46.8
Flax	2.6	4.6	9.44	93.0	2.18	49.0
Flax + *P. bilaiae*	2.6	3.6	7.03	153.8	2.00	40.8
Flax + AMF	1.8	2.4	7.02	44.6	1.32	49.8
Flax + *P. bilaiae* + AMF	2.8	2.3	7.32	78.3	3.38	49.5
Flax + worm castings	3.0	3.4	8.60	79.6	3.14	53.3
LSD (0.05)	2.3	2.7	3.42	158	1.43	9.3

[a]Emergence (emerg.) of a maximum of 10 plants, 5 and 11 days after planting (DAP)

Table 16b. Nutrient concentration (mg/g) and uptake (mg/pot) by **lentil** grown in soil amended with **flax meal** alone or with combinations of worm castings, *Penicillium bilaiae* and arbuscular mycorrhizal fungi (AMF) inoculant.

Treatment	Sht P (mg/g)	Sht N (mg/g)	Sht P (mg/pot)	Sht N (mg/pot)	Sht N:P
Control	4.04	22.79	32.69	181.11	5.6
Flax	3.63	29.45	34.16	277.62	8.1
Flax + *P. bilaiae*	3.30	31.18	24.65	199.40	10.2
Flax + AMF	3.61	27.74	25.22	197.61	7.7
Flax + *P. bilaiae* + AMF	3.83	27.70	23.79	173.09	7.3
Flax + worm castings	3.84	28.09	32.06	239.06	7.3
LSD (0.05)	0.68	1.79	12.02	84.39	2.8

2.3 Sequential extractions for phosphorus:

Total P (Pt) in the Elbow soil was 243 µg/g soil and in the Vonda soil was 182 µg/g soil at the beginning of the experiment (Fig 1). Despite the lower total P values, and soil test Kelowna extraction values (Table 2), organic P (Po) constituted a larger proportion of the total extractable P at the Vonda site (31%) than at the Elbow site (19%).

Both the Elbow and Vonda soils contained roughly equivalent amounts of the resin extractable Pi and $NaHCO_3$ extractable fractions (both Pi and Po combined) (Fig. 2). These fractions represented about 15% of the total soil P. Where the two soils differed considerably is in the NaOH and dilute HCl extracts. The Vonda soil had a larger fraction of both the Po and Pi in the NaOH extractable fraction and a smaller pool of Pi in the dilute HCl extract. While both of these extractions are thought to represent soil P pools of intermediate availability, the NaOH fractions are more available than the dilute HCl fractions.

In the organic amendment experiments the Vonda soil generally supported larger plants as well as higher tissue P concentrations and P uptake than the Elbow soil even though the soil testing values (Table 2) indicate more available P in the Elbow soil. This supports the anecdotal reports from producers, indicating that crop yields are higher than should be attainable with the soil P test data. Based on the soil tests alone, the Elbow soil should support larger yields than the Vonda soil, especially since watering regimes, and temperature were controlled and comparable for the experiments using the two soils.

While the percentage of Po in all of the fractions combined was higher in the Vonda soil than the Elbow soil, the larger difference between the two soils was the Pt extracted with the 0.1*M* NaOH. In the Vonda soil this fraction represented about 35% of the total P in the soil, whereas in the Elbow soil it represented only about 20%. While this fraction is generally considered unavailable, in these organically managed soils without an external P supply, these fractions may become more important than in conventional soils.

Growing a plant on these soils for a single growing season had no discernable affect on the P fractions (data not shown). It is far more likely to be the long-term management over many years and the inherent properties of the soil that affects the P pools and their availability.

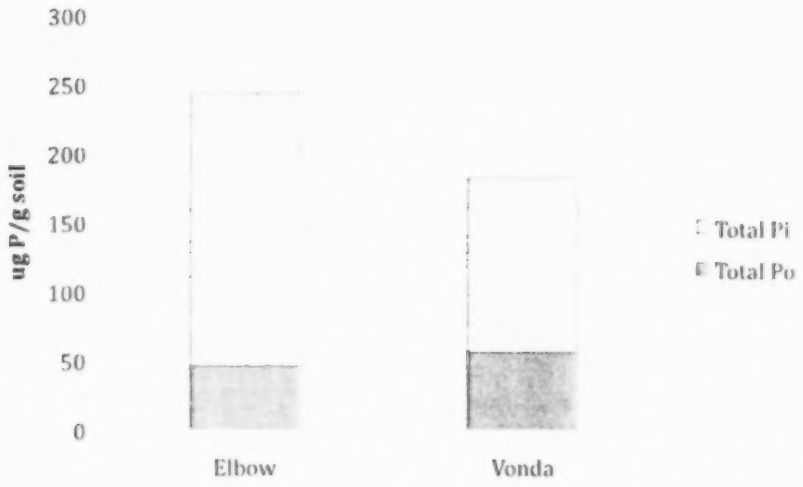

Figure 1. Total phosphorus extracted from the experimental soils at the beginning of the experiments. Values are the sum of the sequential fractions.

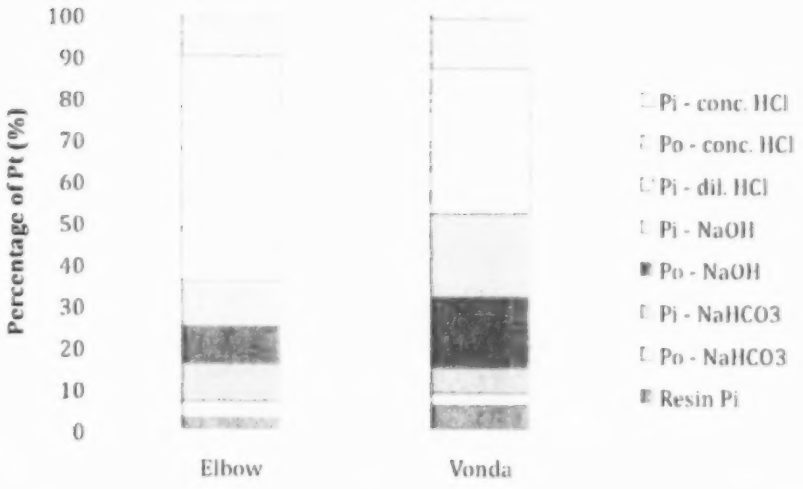

Figure 2. Percentage of total phosphorus extracted in the sequential fractions from the experimental soils.

3. Conclusions and Recommendations

Of the seven organic amendments tested for their effectiveness in supplying nutrients to growing wheat and lentil crops, the three manure-based products (composted sheep manure, fresh and composted poultry manure) were far superior to the other products tested. None of the microbial products (*P. bilaiae*, AMF and worm castings) consistently improved the availability of P or N for uptake. However, there is an indication that *P. bilaiae* may have provided some protection against the negative influences that composted sheep manure had on AMF colonization in wheat. Composted sheep manure applied alone or with either AMF or worm castings reduced percentage root colonization by AMF. The composted sheep manure treatments applied to lentil did not affect AMF colonization. With all of the amendments lentil AMF colonization was affected to a lesser degree than wheat colonization. Applying AMF inoculant had no affect on colonization percentages. The two organically managed soils used in these experiments generally had high AMF propogules inherent to the soils.

Of all of the products tested the aged poultry manure had the largest influence on shoot growth as well as nutrient uptake. Furthermore, this amendment had the least affect on germination and root growth inhibition among all of the amendments tested. The only negative influence the aged poultry manure had was to decrease AMF colonization in wheat, possibly due to inhibition of the AMF by high available nutrient contents. If the poultry manure amendment supplies sufficient nutrients for crop growth, the crop would be less dependent on AMF for enhancing nutrient uptake.

Humic acids did not improve wheat and lentil growth or nutrient uptake. Furthermore application of humic acids decreased germination index for the three species tested in the phytotoxicity bioassay. Humic acids are not recommended.

The remaining three amendments (alfalfa pellets, mustard and flax meals) are all very high organic matter containing amendments. Soils amended with alfalfa pellets required a freezing pre-treatment before the inoculants were applied and the experiments seeded in order to overcome an inhibitory affect of the pellets on seed germination. However, after this freezing treatment there was some improvement in biomass production and nutrient uptake in both wheat and lentil, as well as an enhancement of

AMF colonization. Results from this experiment were more variable than other experiments, perhaps indicating a heterogenous affect of the freezing treatment. Further testing of alfalfa pellets as an amendment in organic production is warranted before recommending it as a valuable amendment, but there does seem to be some potential benefit from this amendment.

The two biproducts of oil extraction processing (mustard meal and flax meal) were generally ineffective at improving growth or nutrient uptake. They seemed to decompose very little over the growing season, probably because of their presumed high content of lignin and cellulose. Although not tested these materials might also benefit from a fall application and winter freeze prior to sowing a crop into them.

Overall, the amendments tended to be more effective, or less negatively effective, when applied to wheat compared to lentil. Water extracts from the amendments tended to have more toxic impacts on lentil germination and root growth than wheat. Those amendments that are plant products (alfalfa pellets, mustard meal and flax meal) also tended to negatively affect lentil nodulation. Economically there is probably no advantage to decreasing biological N fixation by the application of an amendment. If these plant-based high organic matter amendments do prove to be useful and economic for application in an organic systems they might be better applied in the cereal crop phase of a rotation than the legume phase. In contrast, the composted or aged manure products improved nodulation in lentil. Whether or not this translates into more biological N fixation would be interesting to determine.

There is evidence that plants grown in organically managed soils have access to P pools not accounted for in traditional soil tests. Based on soil testing values the Elbow soil should have sustained larger plants, extracting more soil nutrients than the Vonda soil but the opposite was observed. The Vonda soil had a higher proportion of organic P, plus a larger pool of what is considered to be the intermediately available P.

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6. **Appendices** – none

7. Other

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S.S. Malhi, S.A. Brandt, R.P. Zentner, J.D. Knight, K.S. Gill, T.S. Sahota and J.J. Schoenau, 2009. Preventing Nutrient Deficiencies in Organic Crop Production. Poster presentation, Organic Symposium, 22–23 February, Banff, Alberta.

J.D. Knight, 2008. Alternative Methods for Phosphorus Management. AAFC – Scott Research Station General Field Day, 15 July (300 ppl in attendance)

J.D. Knight, 2008. Managing Soil Phosphorus in Organic Systems. AAFC – Scott Research Station Organic Field Day, 15 July (150 ppl in attendance)

J.D. Knight, 2008. Phosphorus Fertility on Organic Farms. Saskatchewan Organic Research Workshop, February 8, Saskatoon, Saskatchewan.

S.S. Malhi, S.A. Brandt and J.D. Knight, 2008. Management Practices for Preventing Nutrient Deficiencies under Organic Crop Production. 16th IFOAM Organic World Congress, June 18-20, Modena, Italy.

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Organic Production. Proceedings of the 2007 Soils and Crops Workshop, February 28-29, Saskatoon, Saskatchewan. (on CD)

Personnel:

Name	Position	Time Commitment
Darin Richman	SRP funded technician	20%
Mark Cooke	Research assistant	50%
Nancy Howes	Research assistant	50% x 8 month/yr
Darren Rowatt	Summer Student	100% x 4 months

Expense Statement: To follow from Financial Services, University of Saskatchewan.